SuperHERO: Next Generation Hard X-Ray Focusing Telescope

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NASA Marshall Space Flight Center

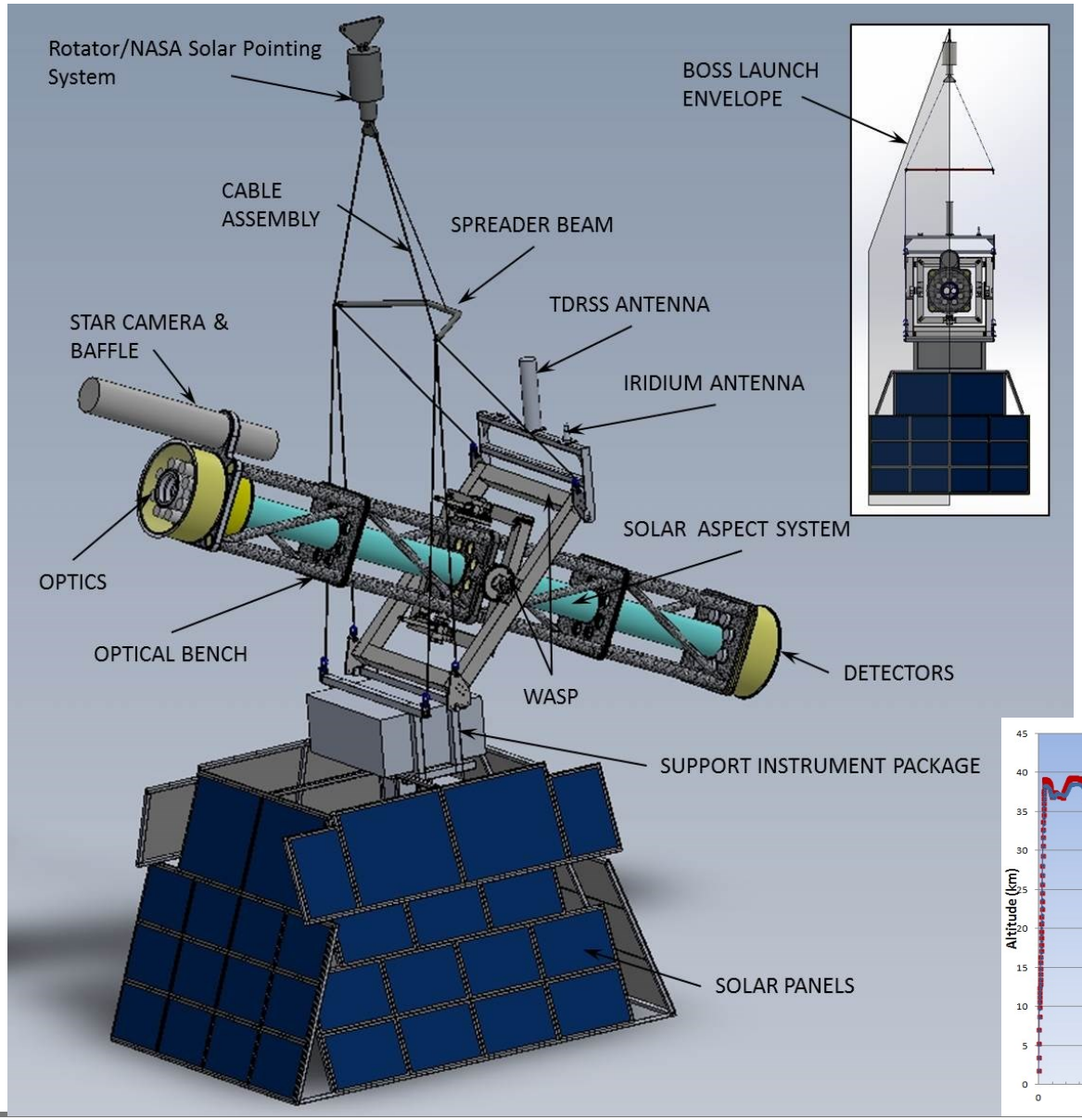
HERO → HEROES → SuperHERO

High Energy Replicated Optics (HERO) : First hard x-ray (20-75 keV) focusing telescope to observe astronomical sources (PI: B. Ramsey, 1998-2012)

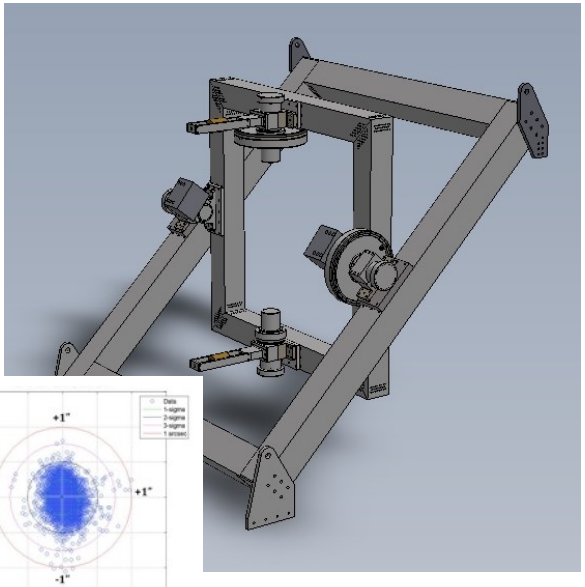
High energy Replicated Optics to Explore the Sun (HEROES) : NASA training program – involved observing the Crab and the Sun during the same flight (PIs: J. Gaskin, S. Christe, 2013-Present)

SuperHERO : Long duration balloon (LDB) payload to observe astronomical sources and the Sun during the same flight at higher sensitivity. Raise TRL of novel solid state detectors and of improved MSFC optics. (PI: J. Gaskin, Proposal Phase)

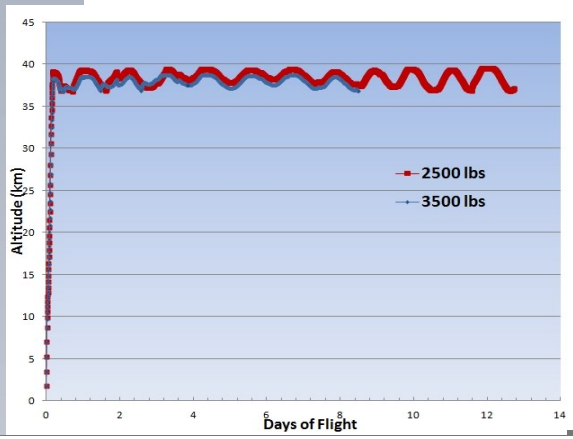
SuperHERO Balloon Payload Concept



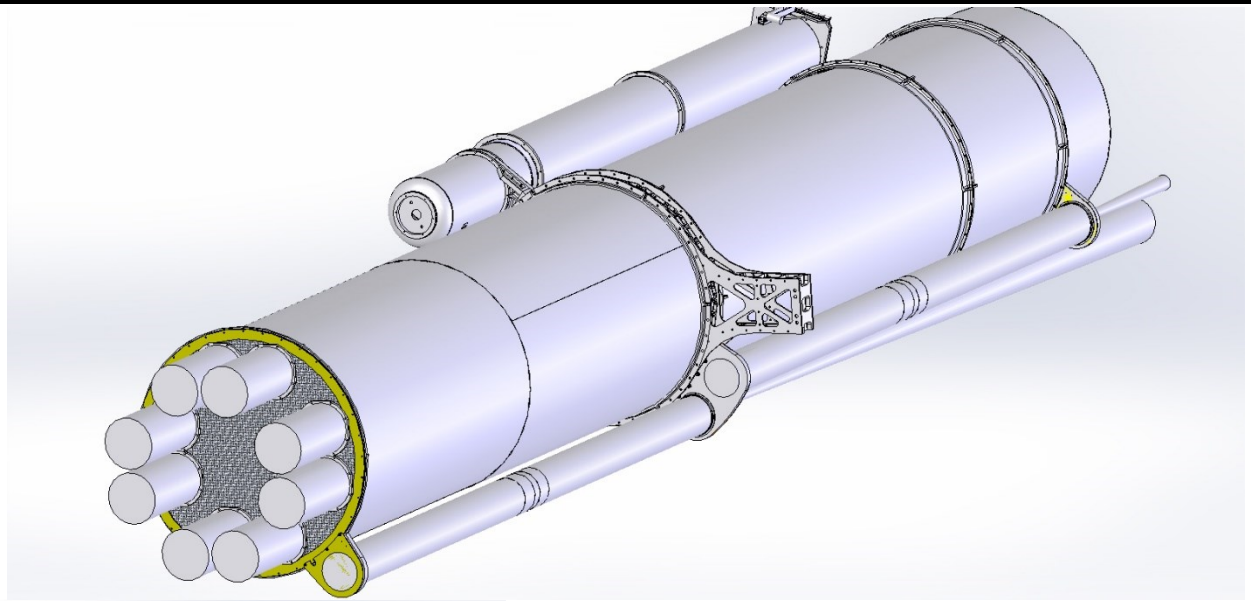
Wallops Arc Second Pointer (WASP)

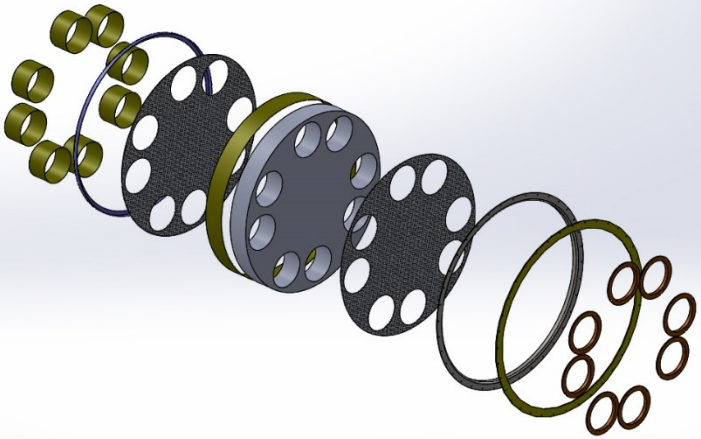


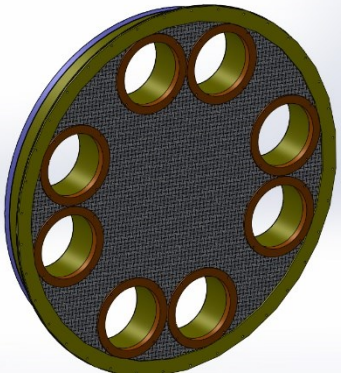
Possible LDB Flight Profile



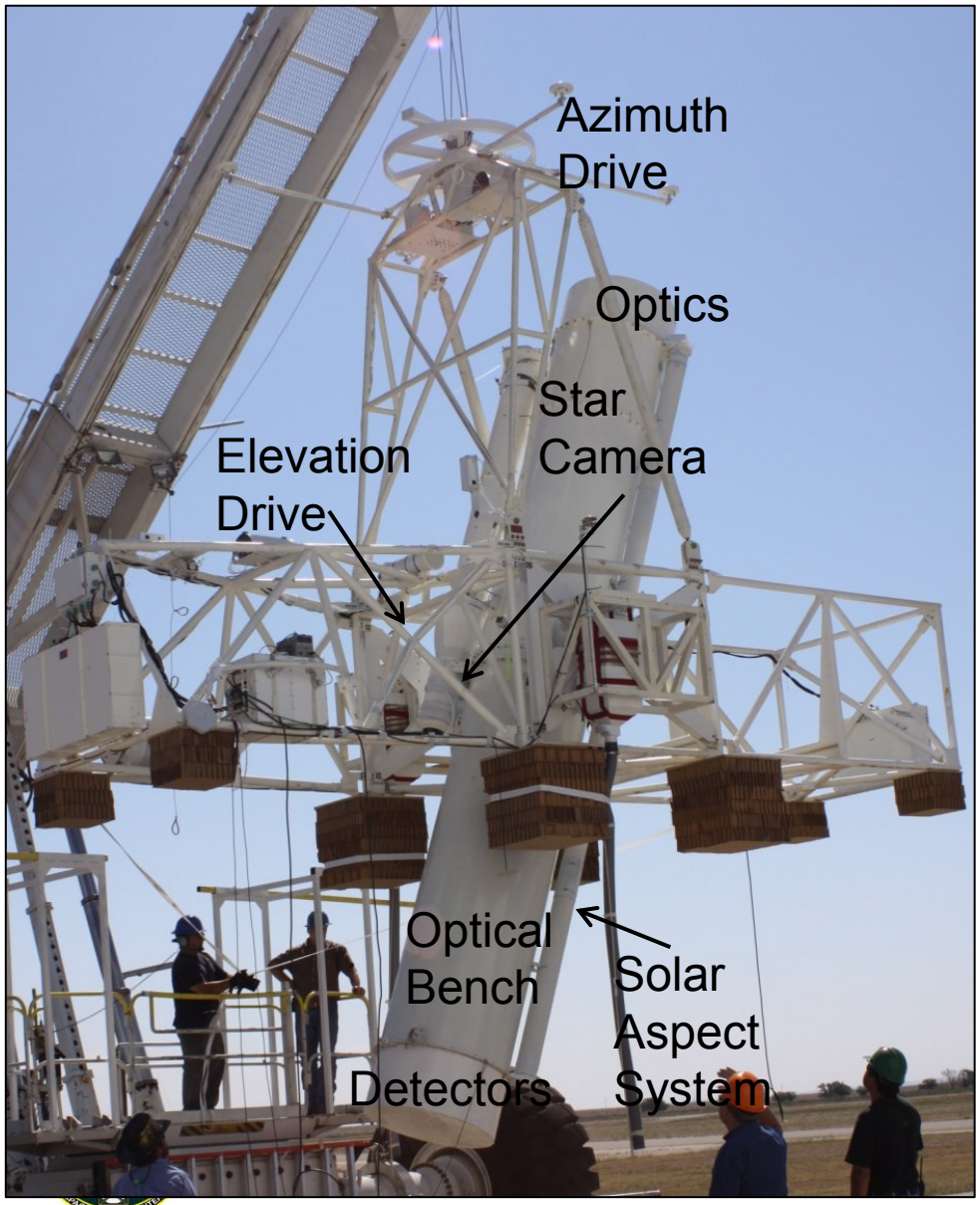
Mechanical – edit to include open truss fro Bruce drawings.

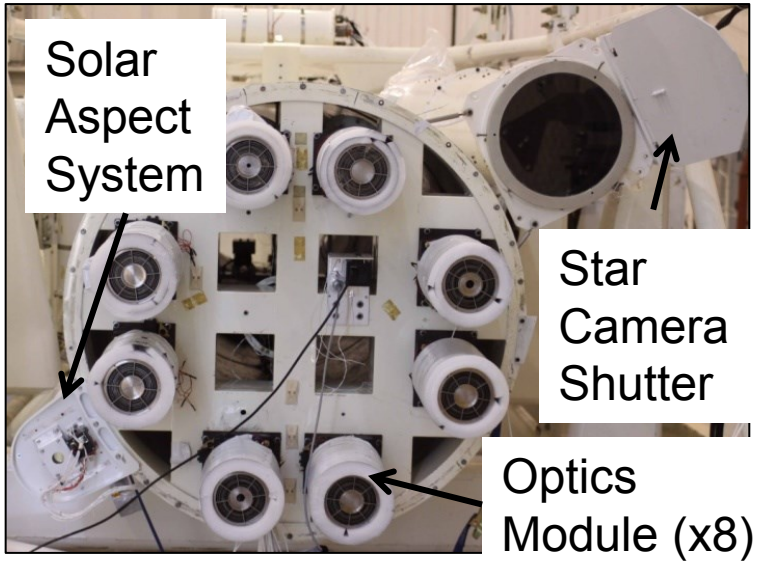


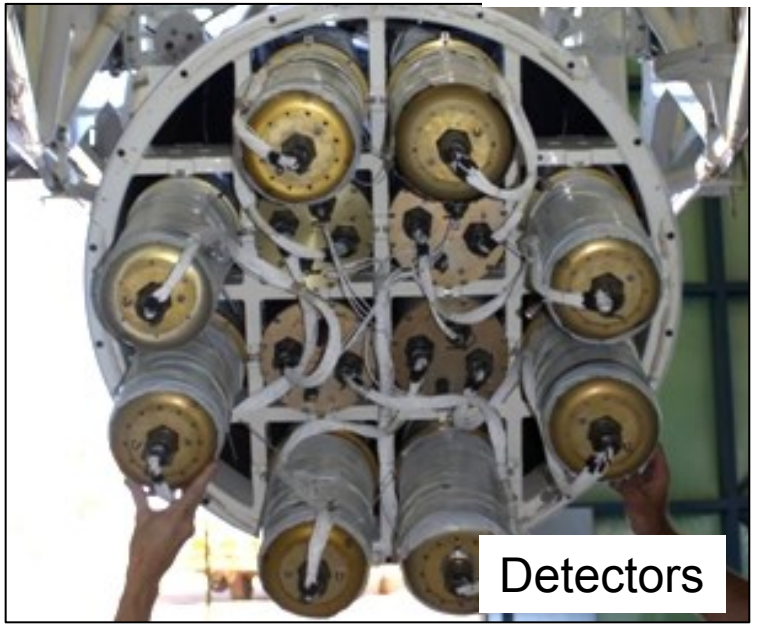




HEROES - Astrophysics Meets Solar





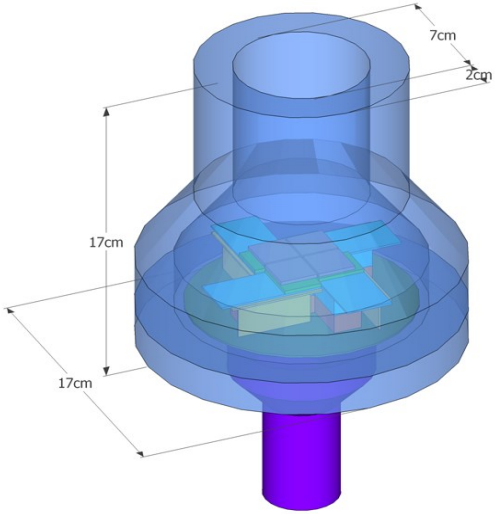


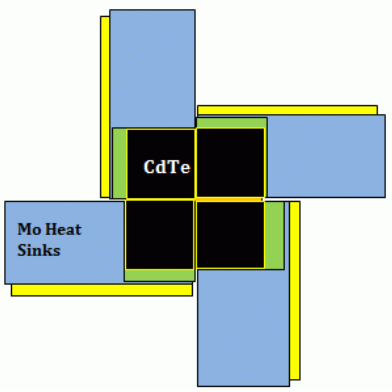
Detectors – RAL/GSFC

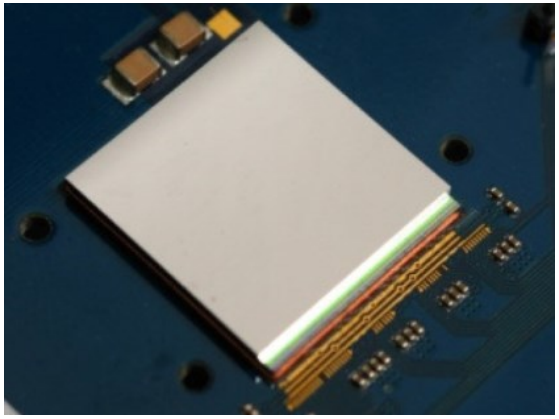
Rutherford Appleton Laboratory (RAL) HEXITEC Fine-Pixel Detectors

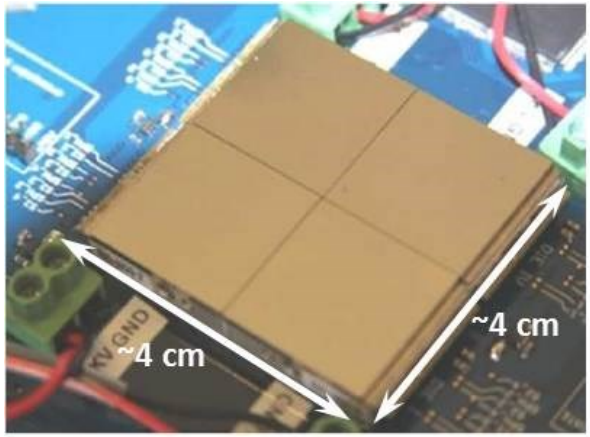
Detectors	HEXITEC (CdTe)
Pixel Size	250 µm
Thickness	1 or 2 mm
Energy Resolution	1.3 % @ 60 keV
Array Size	~4 x 4 cm
Number of Pixels in Array	160 x 160
Max. Processing rate	10,000 evt s^{-1}

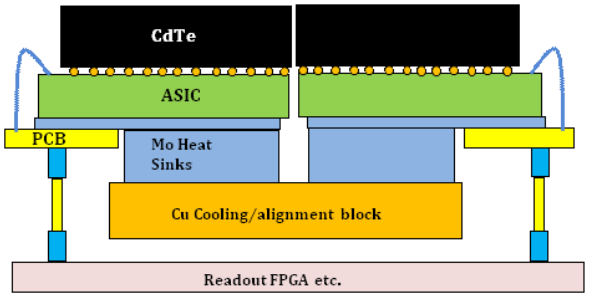
* 5x5 arrays are possible!





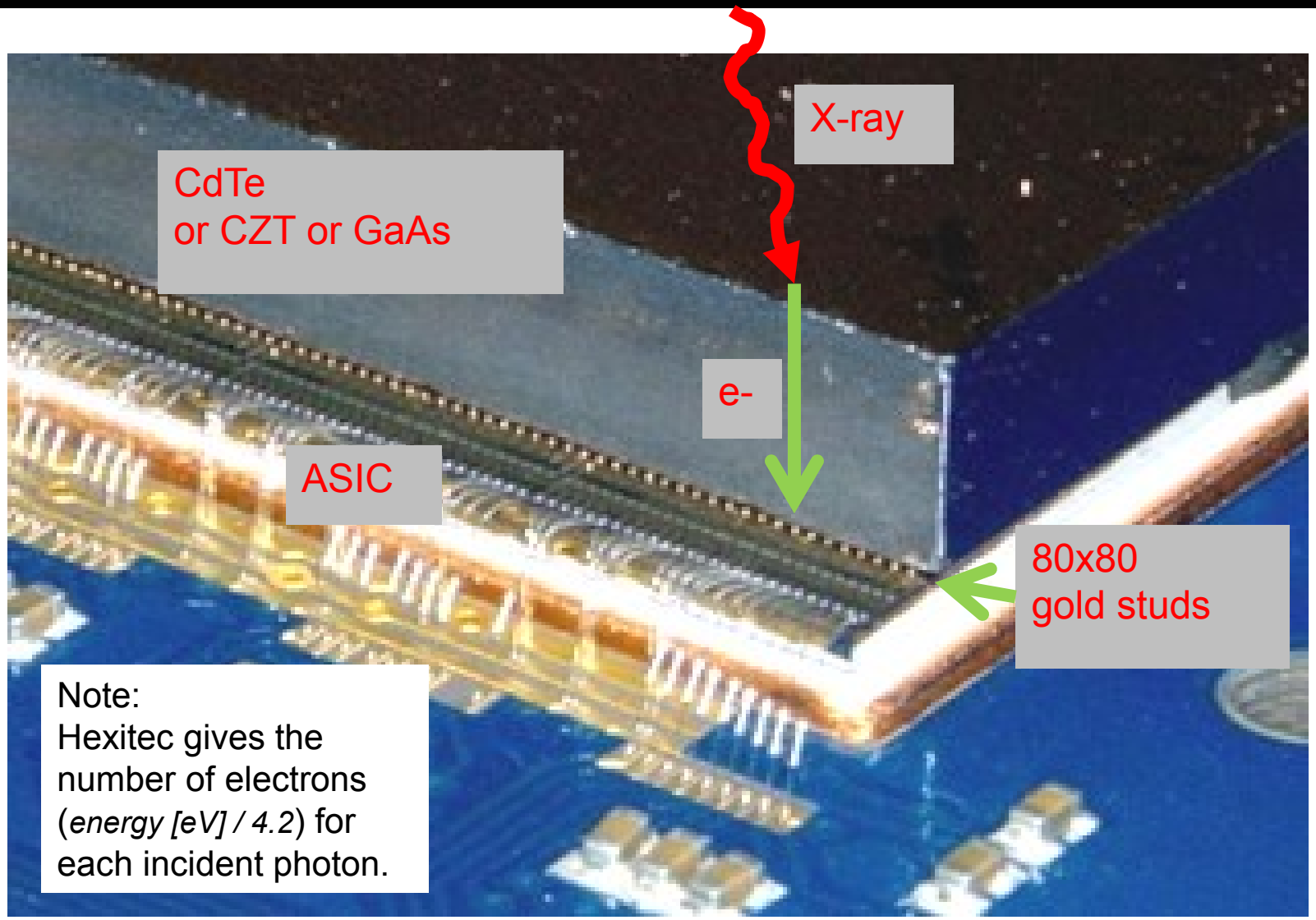






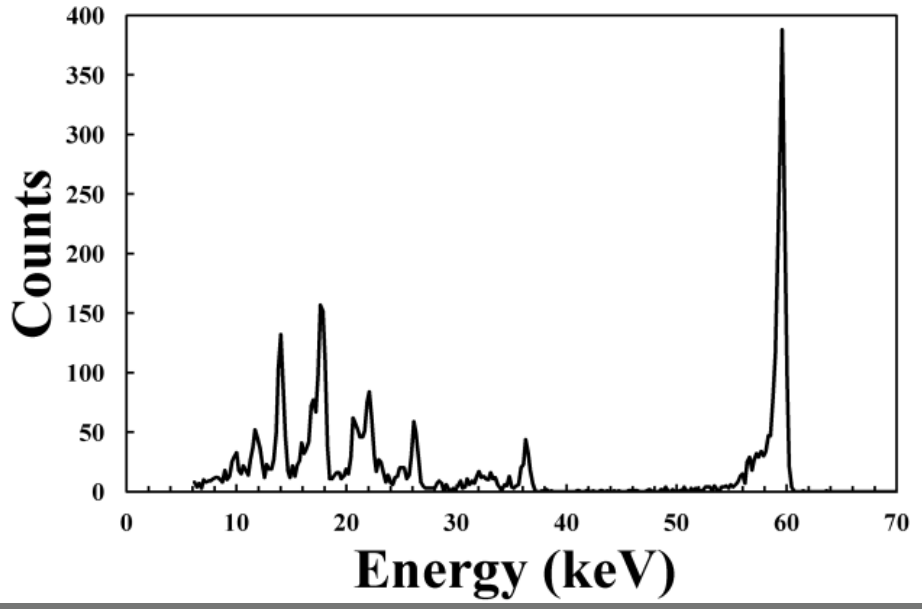
*Multiple publications by P. Seller, M. Wilson & M. Veale

Hexitec X-ray detector - operation



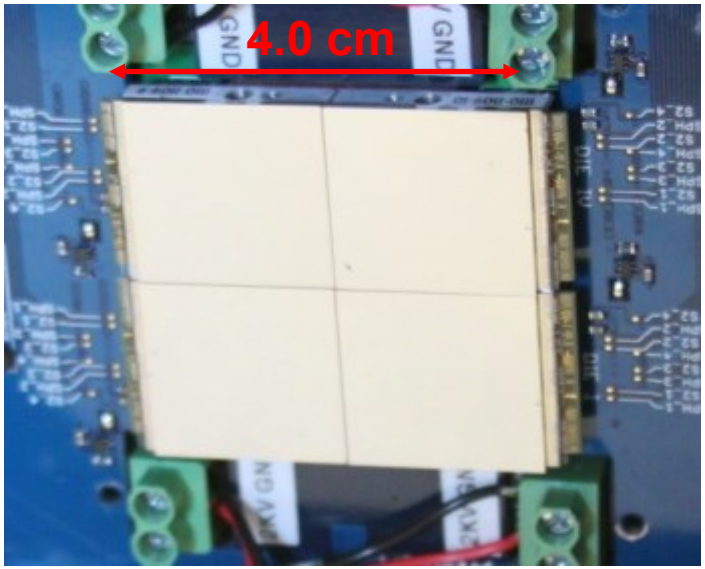
Single Module Hexitec System

- 80x80 pixels
- Energy Range: 4-200 keV
- Max Rate: <10M photons s^{-1}
- 1mm CdTe - 500V Bias
- $FWHM_{@60keV}$ = 0.8 keV
- $FWHM_{@159keV}$ = 1.2 keV
- (second range 12-600keV)
- Camera-Link readout to PC



Multi-Module Array

- Existing ASICs are 3-side-buttable in a flat geometry.
- Modules can be tiled in a (2 x n) geometry with 170um gap.
- Demonstration system produced.
- 16cm^2 array of 2 x 2 CdTe.

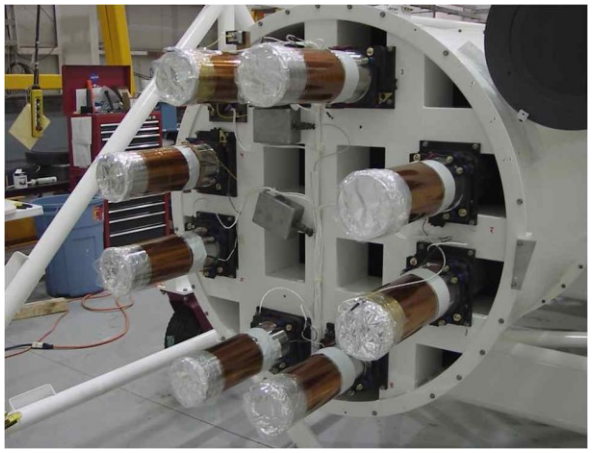


X-Ray Optics at MSFC

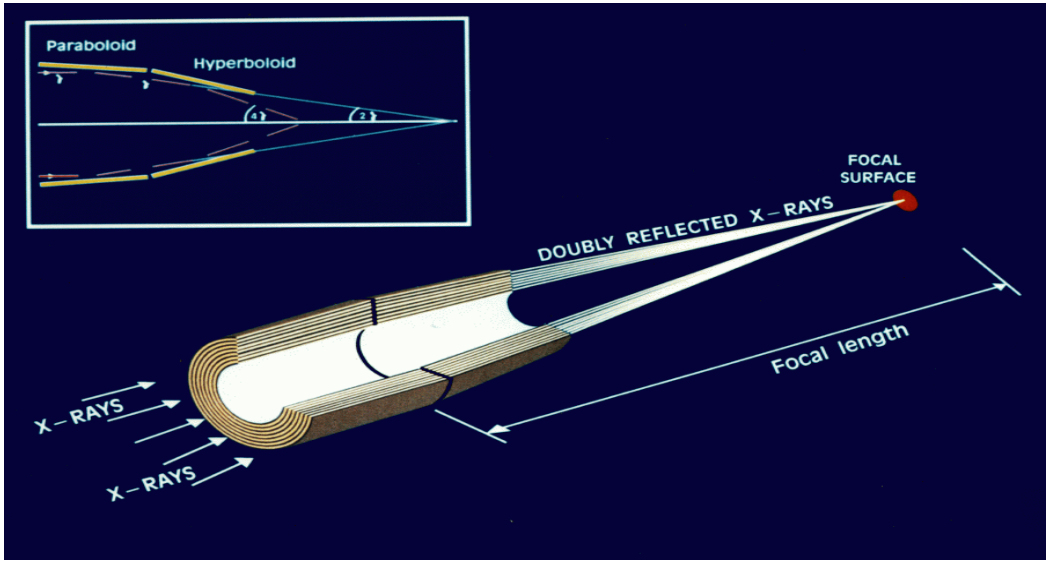
Characteristic	HEROES	SuperHERO
Focal Length	6 m	
Field of View (FWHM)	9 arcmin at 40 keV 5 arcmin at 60 keV	
Mirror Coating	Iridium, 20 nm thick	
Total Mirror Shells (8 modules)	109 shells	152 shells
On-axis geometric effective area	~85 cm^2 at 40 keV	~125 cm^2 at 40 keV
Angular resolution	25 arcsec (HPD) 13 arcsec (FWHM)	20 arcsec (HPD) 7 arcsec (FWHM)

Additional MSFC Efforts for Extended Capability Beyond a Balloon Flight

- **Multilayer Coatings – extend the energy bandwidth**
- **Differential Deposition – significantly improve the angular resolution (goal of 5 arcsec HPD or better)**

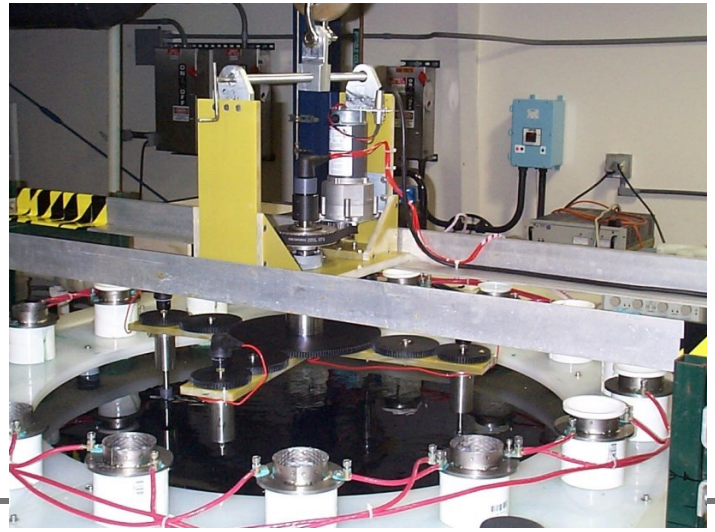


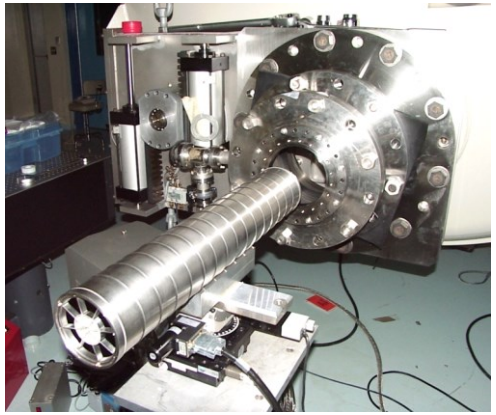
Grazing Incidence Optics



HERO hard X-ray optics are full-shell electroformed-nickel-replicated (ENR) mirrors coated with iridium to enhance high-energy reflectivity.

They are conical approximations to Wolter Type 1 geometry, with a monolithic shell structure containing both “parabolic” and “hyperbolic” segments.

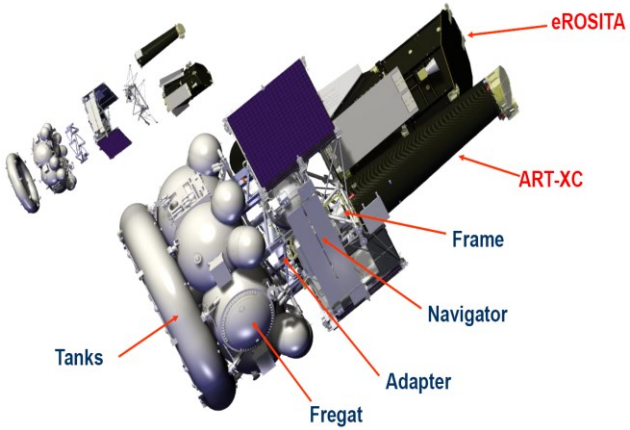




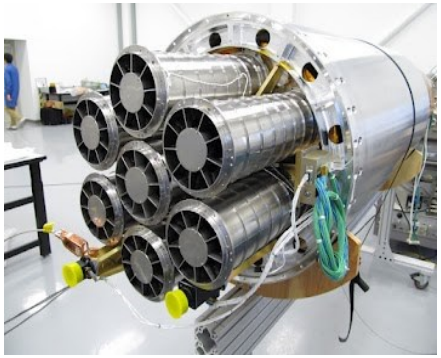
X-Ray Optics Programs at MSFC

ART-XC (Satellite)

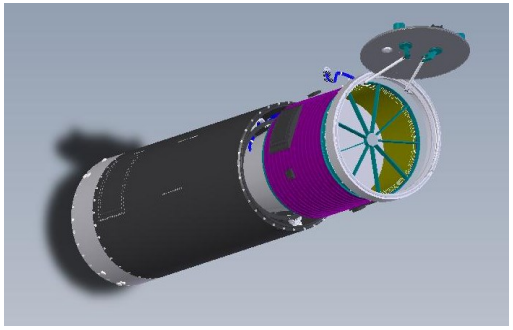
http://xanth.msfc.nasa.gov/



FOXSI (Rocket)



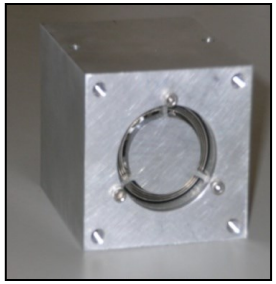
MicroX (Rocket)



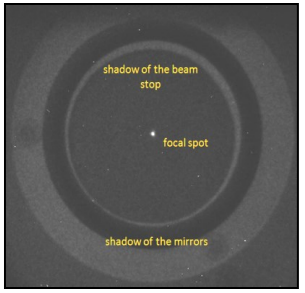
HEROES (Balloon)

Non-Astronomical Applications

Medical Imaging

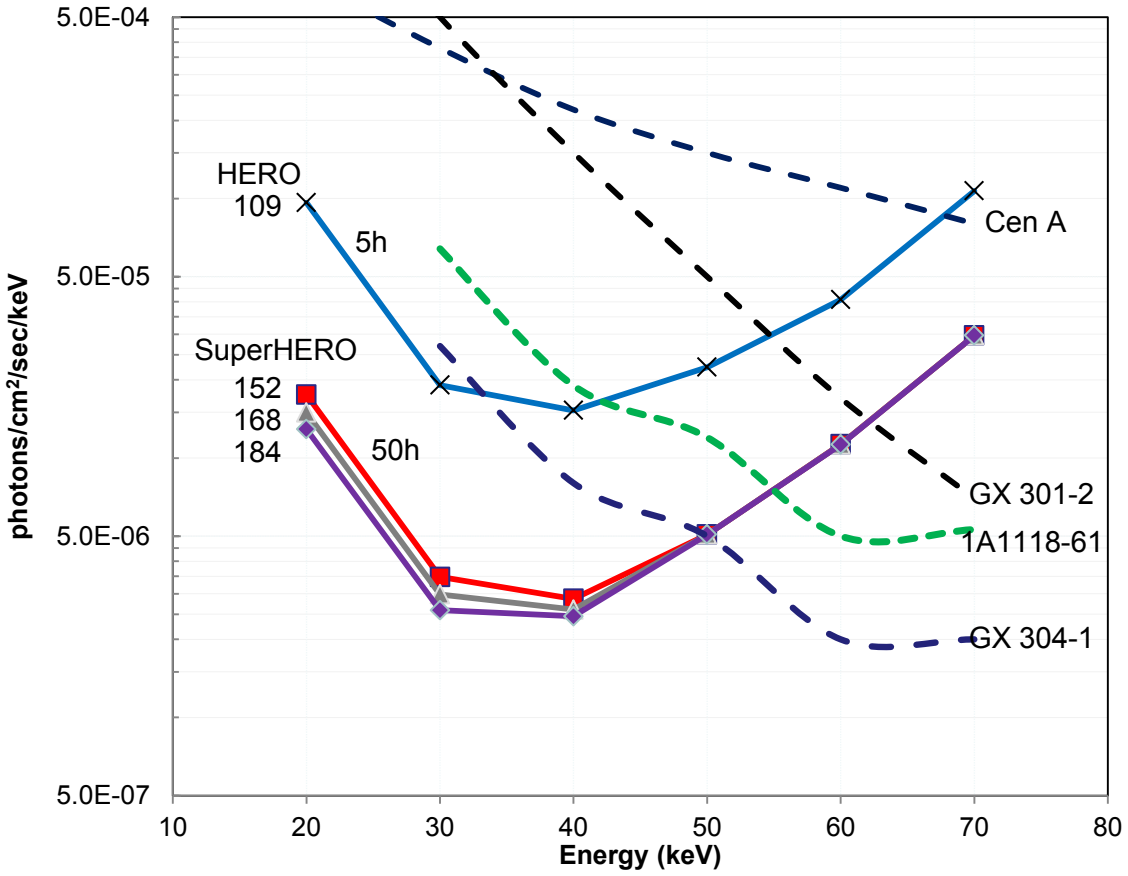


Neutron Imaging

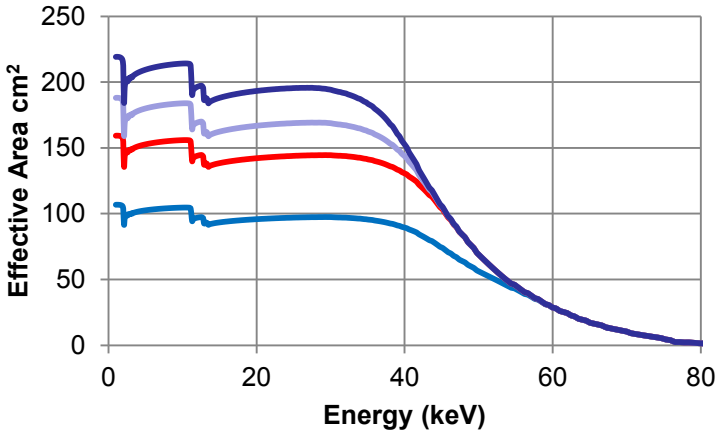


SuperHERO Configuration Trade-Study Ongoing

- Sensitivity



- Effective Area



GX 301-2: V. Borkus et al. 1997, arxiv-astro-ph9712127
Cen A: H. Steinle, 2009, arXiv:0912.2818
GX 304-1 & 1A1118-61: time-averaged source spectra as observed by Swift/BAT

SuperHERO Summary

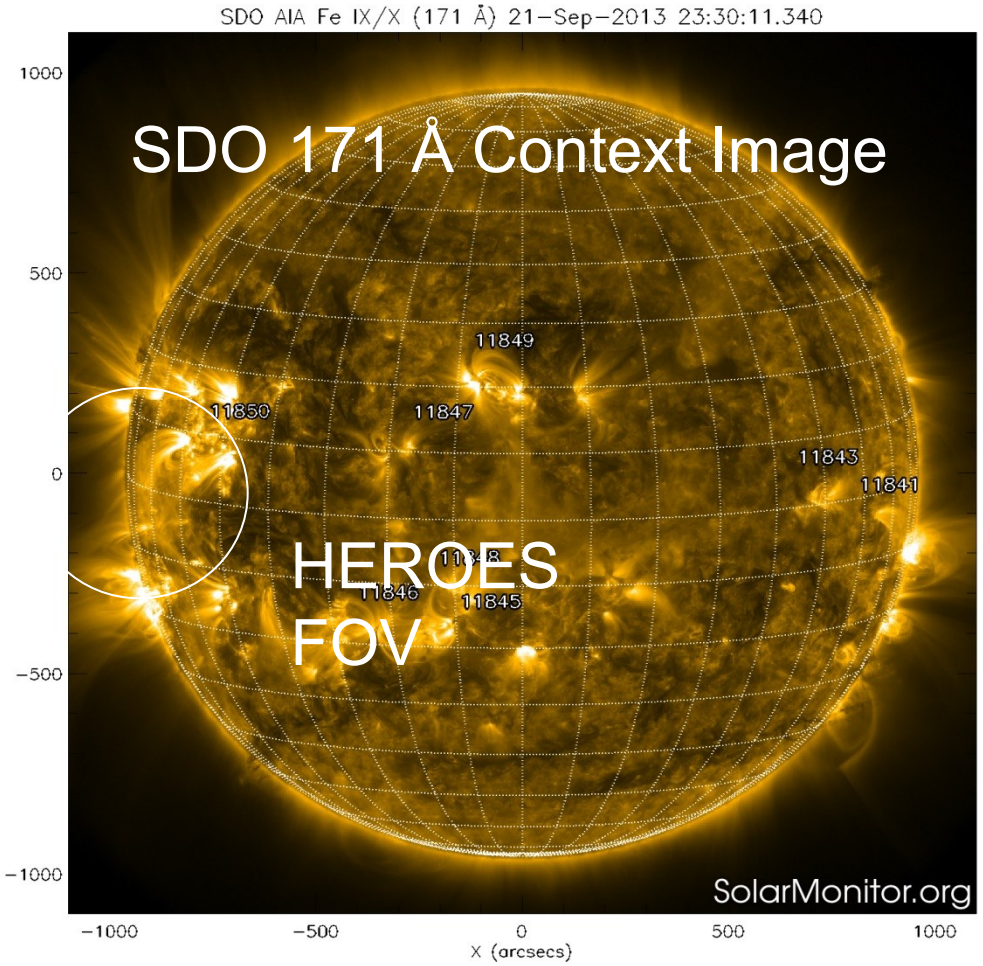
Key Component	Description
Core Instrument	HXR telescope consisting of high resolution optics (fabricated at MSFC) mated to complimentary detectors (developed at RAL and GSFC). • Energy Range: ~20 to 76 keV (upper limit is due to Iridium K edge) • On-Axis Effective Area: ~145 cm^2 at 30 keV (total) • Field of view: ~7 arcmin FWHM at 30 keV
Optics	Electroformed nickel-cobalt alloy mirror shells nested into multiple modules. • Mirror Shells: 152 (19 shells arranged into 8 Modules) • Angular Resolution: ~20 arcsec HPD • Focal Length: 6-m • Mirror Coating: Iridium (20 nm thick) • Shell Thickness: 250 µm
Detectors	These will be tiled into a 2x2 array to cover the full field of view of each mirror module. Active shielding will be used to reduce background. • Detector Type: CdTe pixelated array • Number of pixels: 80x80 pixel arrays, 3-side abuttable • Pixel Pitch: 250 µm • CdTe Thickness: 1 mm • Energy resolution: 1.3% at 60 keV (average pixel FWHM) • Max processing rate: 10kHz, or >5M cts s^{-1} over a 80x80 detector • ASIC can accommodate up to 200 keV with thicker CdTe or CZT

Table 1. Summary of the SuperHERO gondola.

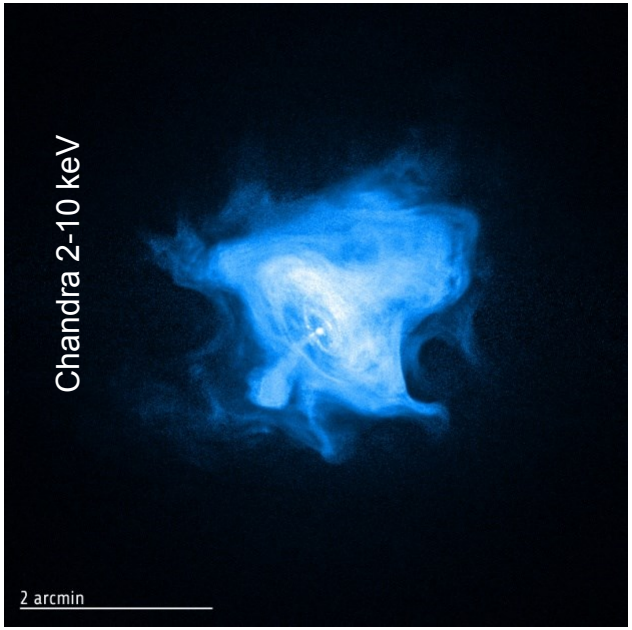
Key Component	Description
Gondola Structure	Commercial Off The Shelf–Graphite fiber-epoxy tubing reinforced with sandwich panel plates with steel tubing center frame. • Science Payload Weight: < 2,500 lbs (estimated from heritage and modeling, includes core telescope) • Power: Solar Panels + Batteries
Pointing System	Wallops Arc-Second Pointer (WASP) • Pointing accuracy: ~1 arcsecond
Rotator	Provides coarse attitude control. • Payload Positioning: to within ~1° of the desired azimuth when combined with the GPS attitude determination unit [13].
Star Camera System	Provides real time solutions to improve fine guidance positions supplied by the inertial gyro system. • CCD : Kodak KAF-6303E • Lens: Takahashi FSQ-106 f/5.0 • Filter: B+W 090 low-pass w/ ~600 nm cutoff • Baffle: 60 cm in length • Mechanical Shutter: implemented during solar observations
Pitch-Yaw Aspect System	Part of the Solar Aspect System, provides 2 independent relative solar aspect solutions and measures the alignment between optics and detectors. • Aspect Solution: to ~10 arcsecs • Optics-Detector Alignment: to ~15 arcsecs
Roll Aspect System	Measures roll during flight to reduce smearing of an x-ray source caused by gondola pendulation and other transient tilts during post-processing. • Roll Knowledge: < 0.3 arcmin (relative)

Preliminary HEROES Solar Observations

- Observed a solar active region for 7 hours!
- The HOPE-developed Solar Aspect System **significantly** exceeded its requirements.
- With its great sensitivity, HEROES has set a new limit on the presence of accelerated electrons in a non-flaring solar active region.
- This will allow us to place new constraints on theories of how the solar corona is heated (the so-called coronal heating problem).

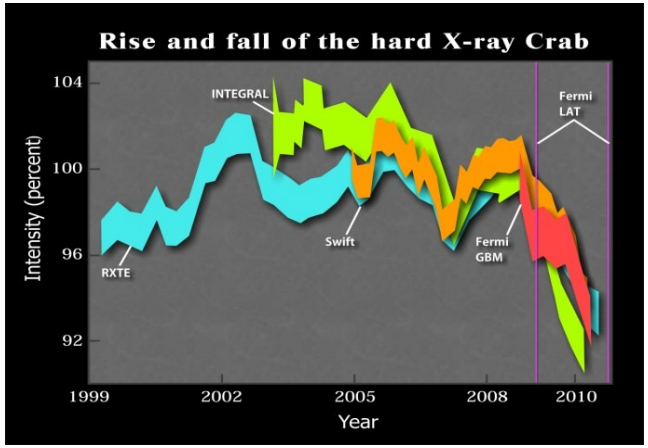


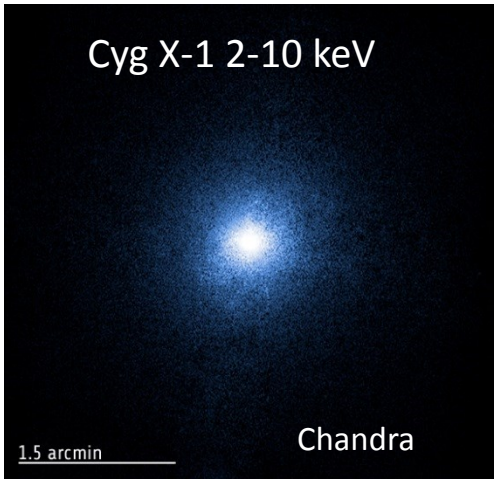
SuperHERO Science from a Balloon

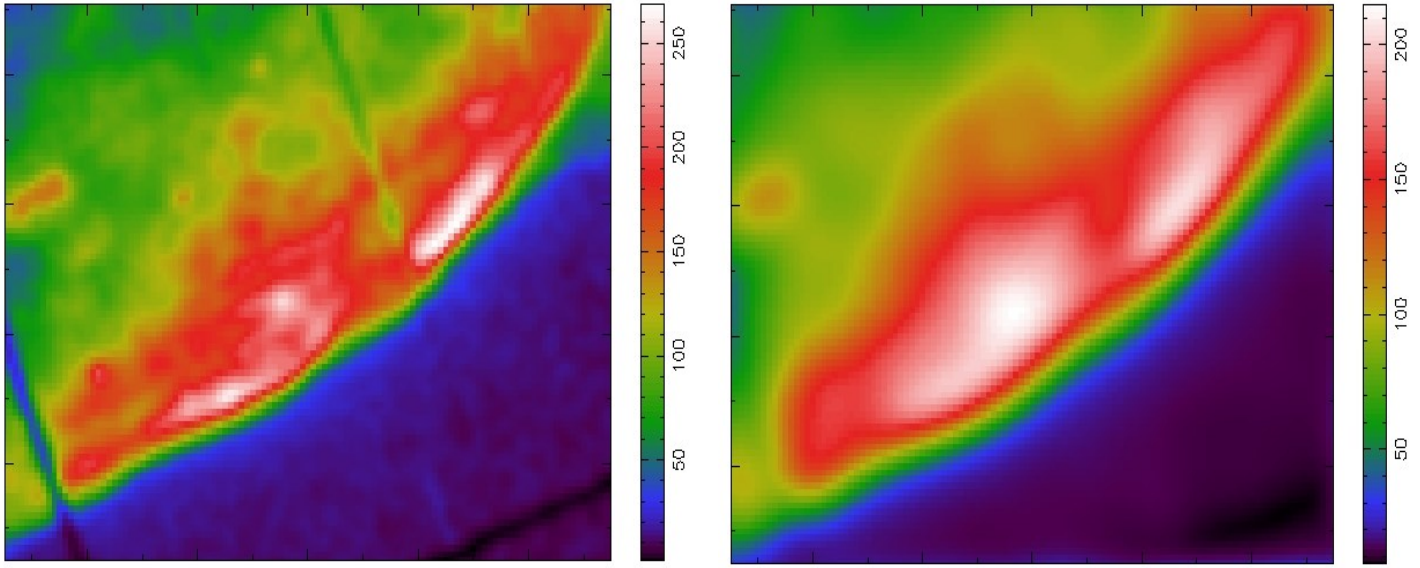


Astrophysics Goals

- SuperHERO will be the first mission to provide the 20" (HPD) angular resolution necessary to distinguish the HXR emission of the rapidly-spinning Crab pulsar from its synchrotron-emitting shocked relativistic electron-positron wind (test flight).
- Provide the highest angular resolution HXR observations to date for a variety of astrophysical objects. Primary targets include the Galactic Center and diffusive shock acceleration sites in supernova remnants (LDB flight).
- Follow-up NuSTAR observations (LDB flight).







Simulated observations comparing the spatial resolutions of SuperHERO (left) and NuSTAR (right). Simulations are of the SW shock region of SN 1006 made with data from XMM-Newton using photons in the 2-10 keV range convolved with circular Gaussians representing the respective HPD of the two HXR telescopes. Note the XMM/MOS chip gaps are still visible at the SuperHERO resolution. Images are 10 arcmins x 8arcmins, slightly larger than the HXR telescopes fields of view.

National Aeronautics and Space Administration

The View from NASA

Astrophysics

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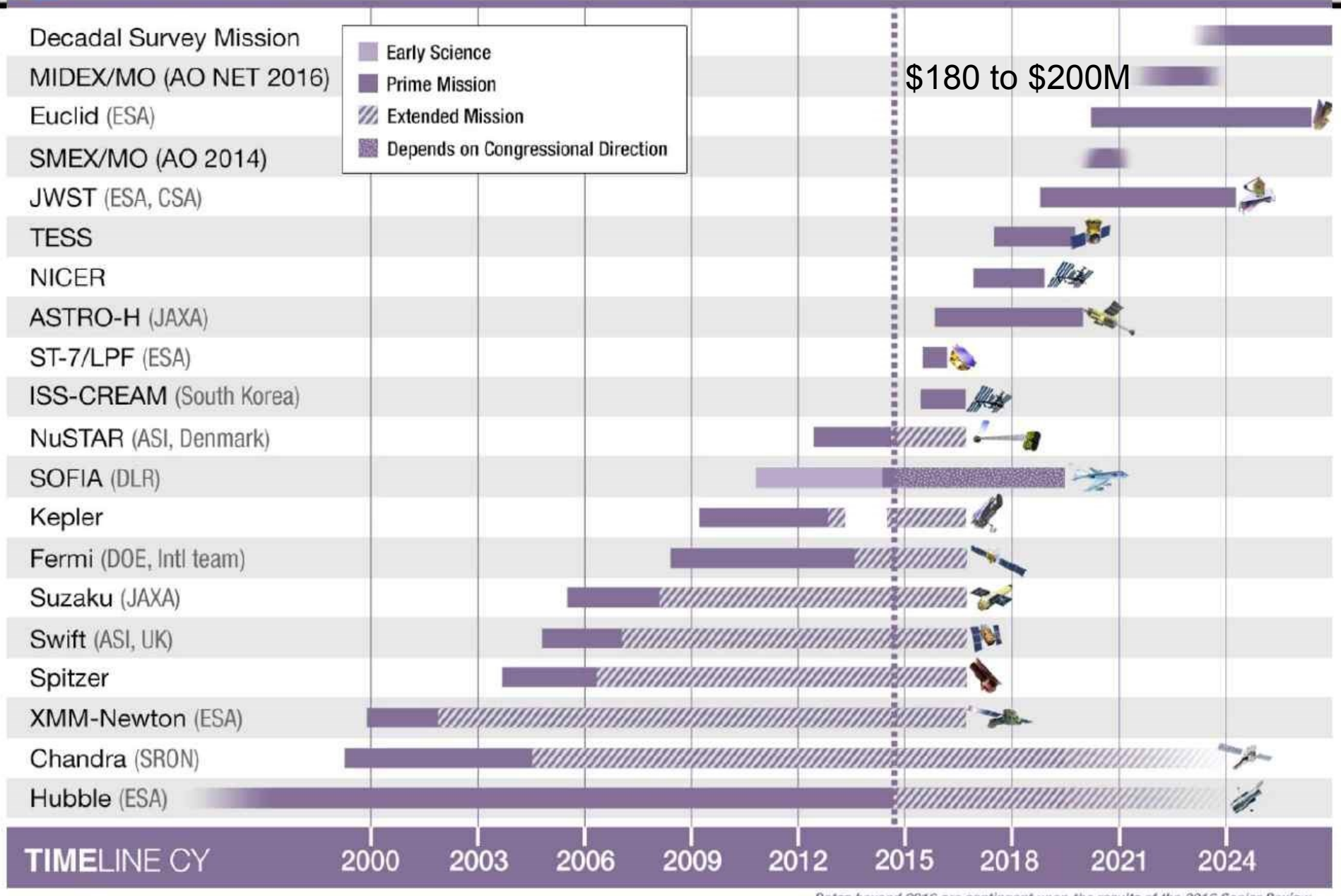
www.nasa.gov

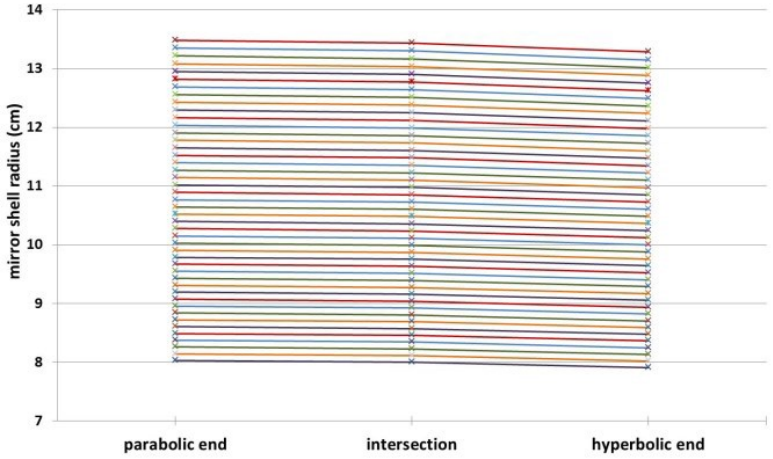
WFIRSST Conference, Pasadena
November 19, 2014

Astrophysics Timeline

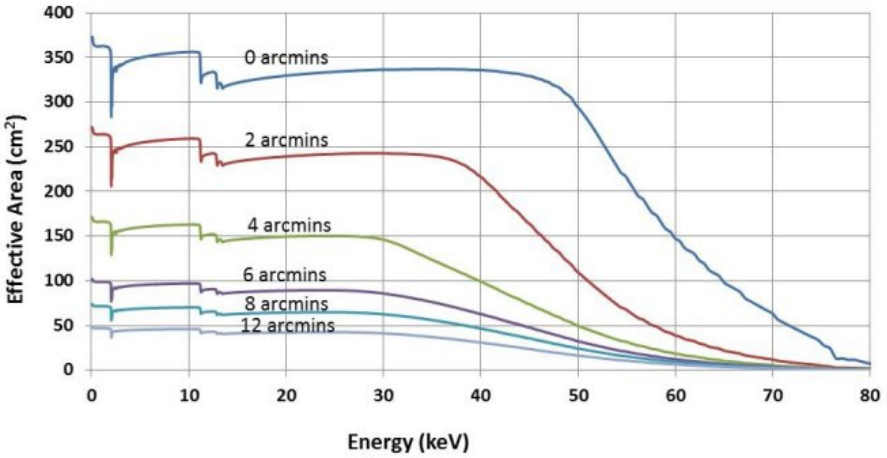


Dates beyond 2016 are contingent upon the results of the 2016 Senior Review

SuperHERO – Possible Satellite Configuration



The SuperHERO satellite configuration would consist of 135 x-ray mirror shells configured into 3 modules (45 nested shells per module.)



Plot of the simulated total effective area for the SuperHERO space-based optics configuration (on- and off-axis).

Optics	MSFC-Full Shell
Mirror shells per module (3 modules total)	45 shells
Focal Length	20-m
Mirror Coating	Multilayer (TBD)
On-axis geometric effective area	335 cm^2 at 40 keV 150 cm^2 at 60 keV
Angular resolution	<5 arcsec (HPD) *Goal*
Field of View (FWHM)	5.6 arcmin at 40 keV 2.7 arcmin at 60 keV

Detectors	HEXITEC (CdTe)
Pixel Pitch	250 μm
Thickness	1 or 2 mm
Energy Resolution	1.3 % @ 60 keV
Array Size	~4 x 4 cm
Number of Pixels in Array	160 x 160
Max. ASIC Processing rate	10,000 evt s^{-1}

Differential Deposition

- ***What***
  - Differential deposition is a technique for correcting figure errors in optics
- ***How***
  - Use physical vapor deposition to selectively deposit material on the mirror surface to smooth out figure imperfections
- ***Why***
  - Can be used on ***any type*** of optic, full-shell or segmented, mounted or unmounted
  - Can be used to correct a wide range of spatial errors. Could be used in conjunction with other techniques… e.g. active optics.
  - Technique has been used by various groups working on synchrotron optics to achieve sub-µradian-level slope errors

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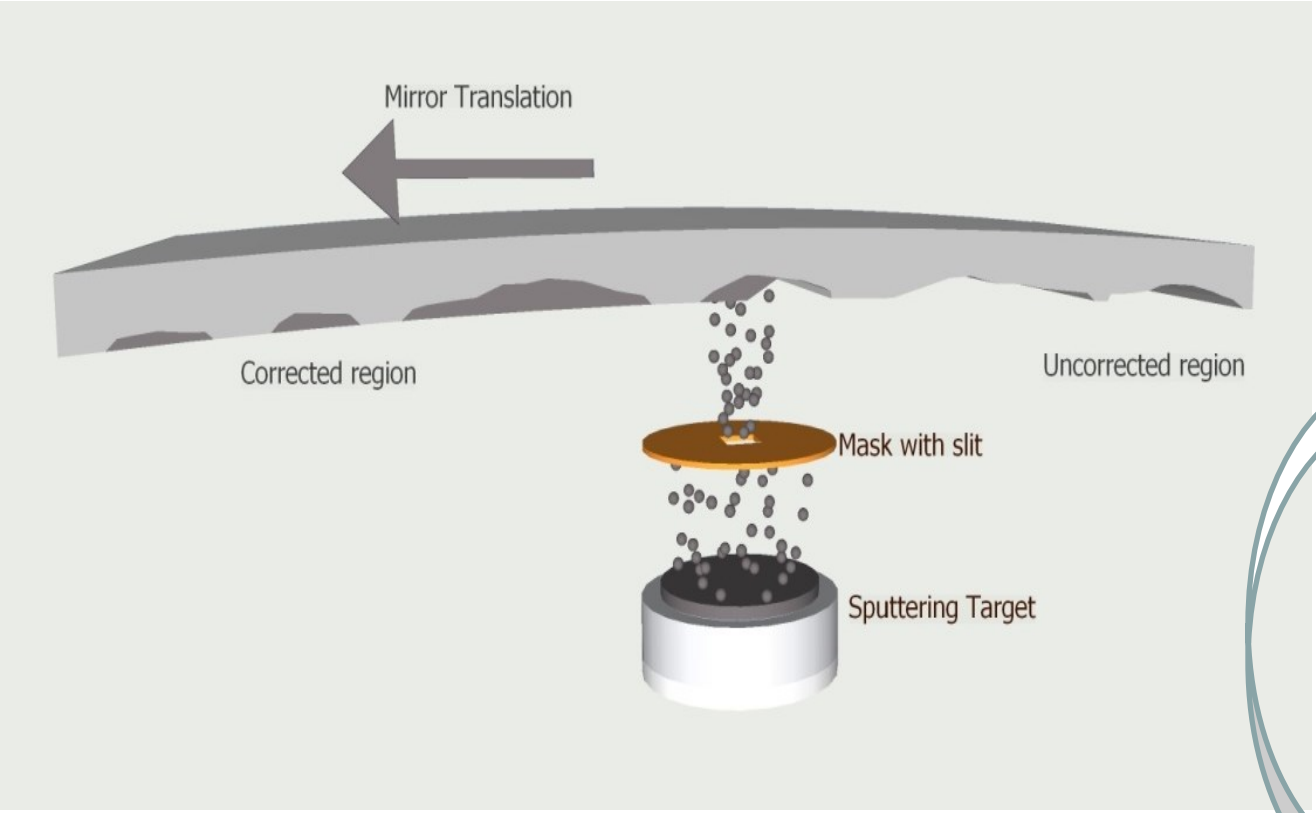
Coating Configuration



Surface profile metrology

Develop correction profile "Hitmap"

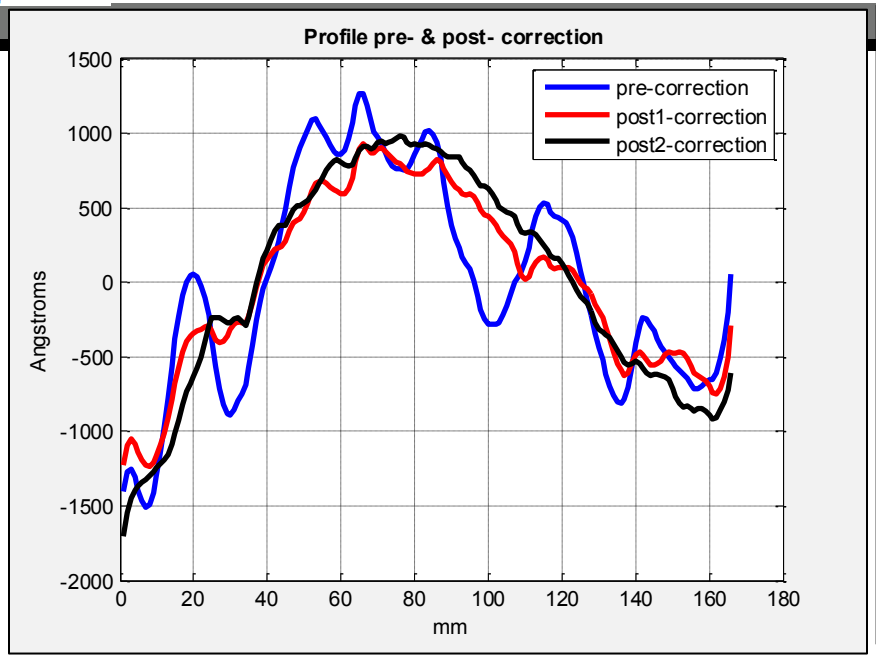
Simulations – translation velocity of shell

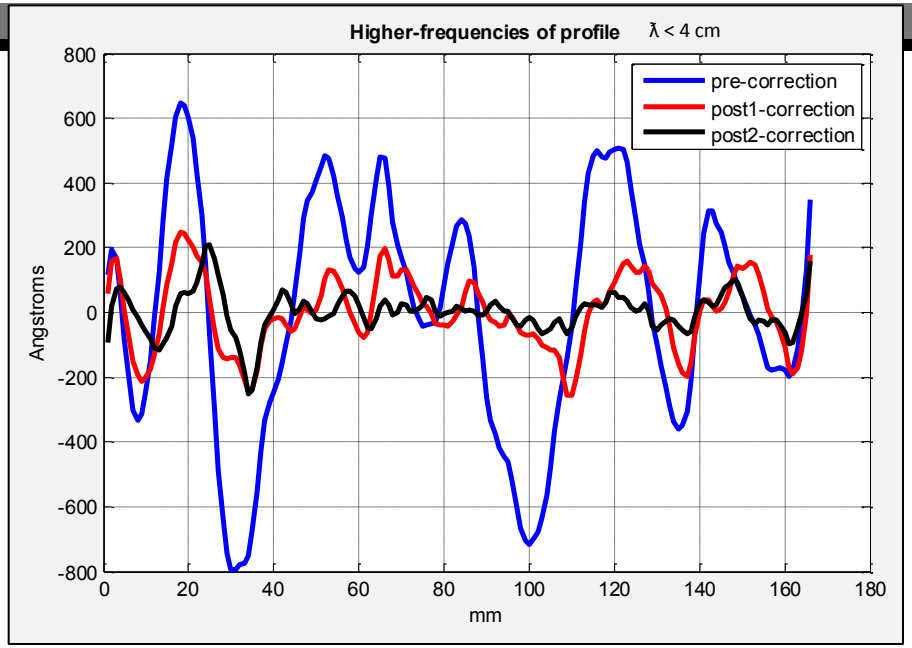
Differential deposition

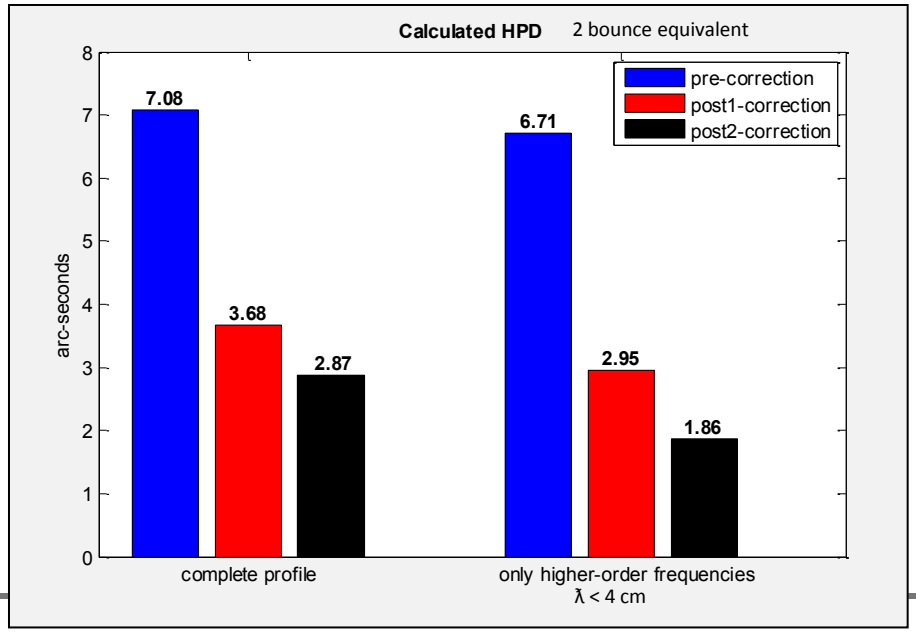
Surface profile metrology

X-ray testing

Test coating run # 1: horizontal chamber, 150 mm diameter shell
P-end, pre- and post- two stages of correction



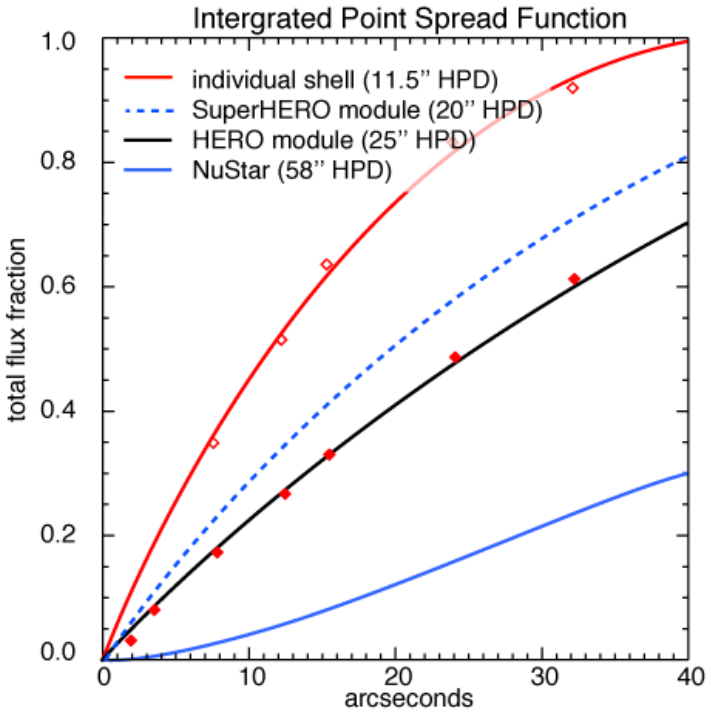




SuperHERO Vs NuSTAR

Detectors	HEXITEC (CdTe)	NuSTAR¥ (CdZnTe)
Pixel Size	250 μm	600 μm
Energy Resolution	1.3 % @ 60 keV	1.3 % @ 60 keV
Array Size	~4 x 4 cm	~3.84 x 3.84 cm
Number of Pixels in Array	160 x 160	64 x 64
Max. Processing rate	10,000 evt s^{-1}	400 evt s^{-1}

¥Harrison, F., et al. [2013] *ApJ*, 770, 103

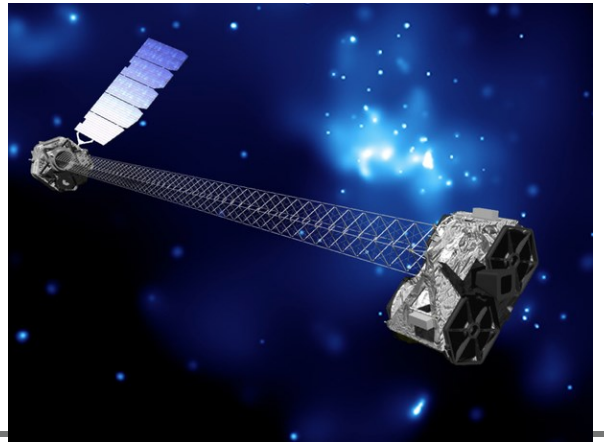


Additional MSFC Efforts for Extended Capability

- Multilayer Coatings – extend the energy bandwidth
- Differential Deposition – significantly improve the angular resolution (goal of 5 arcsec HPD or better)

Hard X-ray Astrophysics (SuperHERO Satellite / NuSTAR)

- Probe Obscured Active Galactic Nuclei (AGN)
  - Cosmic X-ray Background (unresolved x-ray sources)
- Study the population of HXR compact objects and diffuse molecular clouds in the Galaxy
  - BHs, Neutron Stars, White Dwarfs
  - Morphology & Diffuse emission (origin of XRB of Galaxy)
- Study the non-thermal radiation in young supernovae remnants
  - Synchrotron emission (acceleration of ultrarelativistic charged particles in a magnetic field)
  - Particle acceleration & origin of cosmic rays
  - ^{44}Ti, important for understanding explosion mechanisms and stellar evolution
- Blazars & the Nature of Relativistic Jets
  - Very energetic gamma-ray emission from LOS relativistic jets in active galaxies
  - Particle acceleration process in jets is not well understood
- Pulsar Wind Nebula
  - Particle acceleration properties not well understood
  - Composition of the wind is unknown



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